LASER COMPONENTS

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Title I designs are complete for a number of critical NIF components, including the NIF optical pulse generation system, the amplifiers and their associated power conditioning system, and the Pockels cell. Each of these systems follows the line-replaceable-unit philosophy, modularizing wherever possible. Prototype testing and component evaluations will proceed during Title II (final design), as we continue to look for ways to further simplify designs, optimize costs and performance, and enhance the safety and reliability of these systems.

Introduction

In this article, we review the laser's full-aperture active components—the amplifiers, their associated power conditioning system, and the Pockels cell. We also discuss the optical pulse generation system that prepares the input pulse for injection into the main laser beamlines. System control functions for alignment, positioning, and wavefront correction are covered in a separate article on laser control systems (p. 180).

The hardware for these components resides in the laser bay and capacitor banks. A portion of the optical pulse generation system—the master oscillator room—is in NIF's central operations area.

Each system has a development effort associated with it to address key technologies and design issues. For instance, the Title I amplifier design—a close-packed 4 × 2 aperture configuration, with a larger number of flashlamps and cassettes and flashlamp cooling—was developed in LLNL's AMPLAB. For the power conditioning system, we are testing and evaluating switches at Sandia National Laboratories and capacitors at LLNL, as well as developing pulsed power components with industrial partners including Primex and American Control Engineering. Similarly, we are completing optical system development for the optical pulse generator's preamplifiers on the Preamplifier Testbed at LLNL, and completing analysis of our Pockels cell design in a dedicated development lab.

Another common thread is our focus on reliability and failure modes for these components. During Title I, we identified failure modes that could cause significant delays or costs. The most serious for the pulse generation system involved cleanliness, excessive output power or energy, or failure to put the appropriate bandwidth on the output pulse. To address these issues, we will be developing fail-safe systems for beam modulation and power; and energy limiters in detail as part of Title II. For amplifiers, we have modularized the system to the point where the only thing that can cause damage over a large fraction of the laser is an earthquake. Pockels cells are in a similar situation. For power conditioning, the biggest concern is a fault mode or a fire. We are ensuring in Title I and Title II design that none of these issues present credible risks.

There have been many changes to NIF since the conceptual design (CD). Those that have a significant impact on design in these areas are the bundle change from 4 × 12 to 4 × 2, the laser architecture change from the 9-5-5 amplifier configuration to 11-5 (not to preclude a change to 11–7), the number of preamplifiers changing to 48 from 192, and the added requirements for active flashlamp cooling in the amplifiers and for smoothing by spectral dispersion (SSD) in the front-end. Finally, for power conditioning, the very large rigid transmission lines that were part of the CD have been replaced by flexible lines to simplify interfaces with the facility and other equipment.

In this article, we describe the Title I design of each of the systems and summarize their Title II activities as well.

Optical Pulse Generation System

The primary function of the optical pulse generation system (OPG) is to generate, amplify, spatially and temporally shape, and inject an optical pulse into the plane

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of the transport spatial filter pinhole, where it enters the amplifier system. The baseline Title I configuration described here is for 192 independent beamlines, although we plan to change the design to a 48-preamplifier module (PAM) system early in Title II to reduce cost. Design drivers include delivering a square-shaped beam of 1.053 µm, with a maximum pulse length of 20 ns to the injection optics. The intensity profile of the beam must be shaped to precompensate for any gain nonuniformities in the large-aperture section of the laser. For a square beam 22.5 mm on a side, the beam pointing stability must be 9.7 µrad. Another design driver is that the OPG optics and other components need to withstand a 25-J back-reflection without damage. Finally, the OPG needs to be able to deliver at least an 8.8-J pulse to the transport spatial filter (TSF).

The OPG system and its Preamplifier Maintenance Area (PAMMA) are centrally located in the Laser Target Area Building (LTAB) (Figure 1). The OPG system includes the master oscillator room (MOR), where the pulse is generated; the PAM, where the beam is initially amplified and shaped; and the preamplifier beam transport system (PABTS) and the injection system, which relay and focus the beam through the TSF in the main laser system (Figure 2). We include the injection system in our discussion, even though it is sometimes considered separate from the OPG system. The input sensor is also located in the OPG area, between the preamplifier and its associated beam transport system. For information about this diagnostic system, see "Laser Control Systems" on p. 180 of this *Quarterly*.

The master oscillator room (MOR) is where the parameters of the beam are determined: wavelength, bandwidth, pulse shape, and pulse timing. We designed the MOR to be highly flexible to accommodate changes in experimental requirements. The MOR uses fiber-optic technology extensively: five fiber-optic subsystems connect optically in a series (Figure 3), before fiber-optic cables deliver the pulses to the preamplifiers. At the start of this optical chain, a fiber-ring oscillator produces a single pulse, on the order of 1 nJ, which then passes through high-frequency waveguide modulators that apply phase modulation for suppressing stimulated Brillouin scattering (SBS) and for smoothing by spectral dispersion (SSD). A "chopper" then selects a time window for the pulse to avoid overdriving the fiber amplifier chain. The SBS bandwidth is controlled by a four-part, robust, fail-safe system that will preclude optics damage due to SBS. Next, the pulse is amplified by a single-fiber amplifier before entering an array of four-way splitters, dispersion compensators, and fiber amplifiers that split and amplify the single pulse into 192 of equal energy (Figure 4). Each optical pulse is then shaped by an amplitude modulator. The modulator can form a pulse 200 ps to 20 ns long, with 500:1 contrast, 250-ps shaping resolution, and 5-ps timing resolution. Finally, the pulses travel through MOR fiber-distribution racks holding timing fibers, where different timings can be selected for target backlighting, etc. From here, each pulse travels by fiber-optic cable to a PAM in one of the two laser bays.

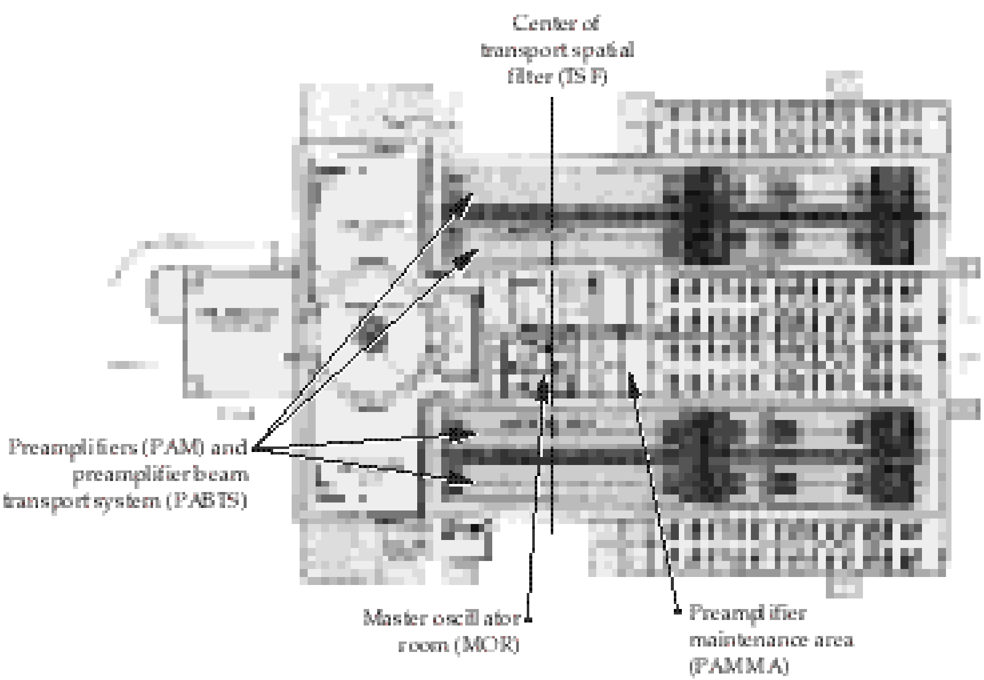


FIGURE 1. The OPG is centrally located in the LTAB (plan view). (40-00-0997-2100pb01)

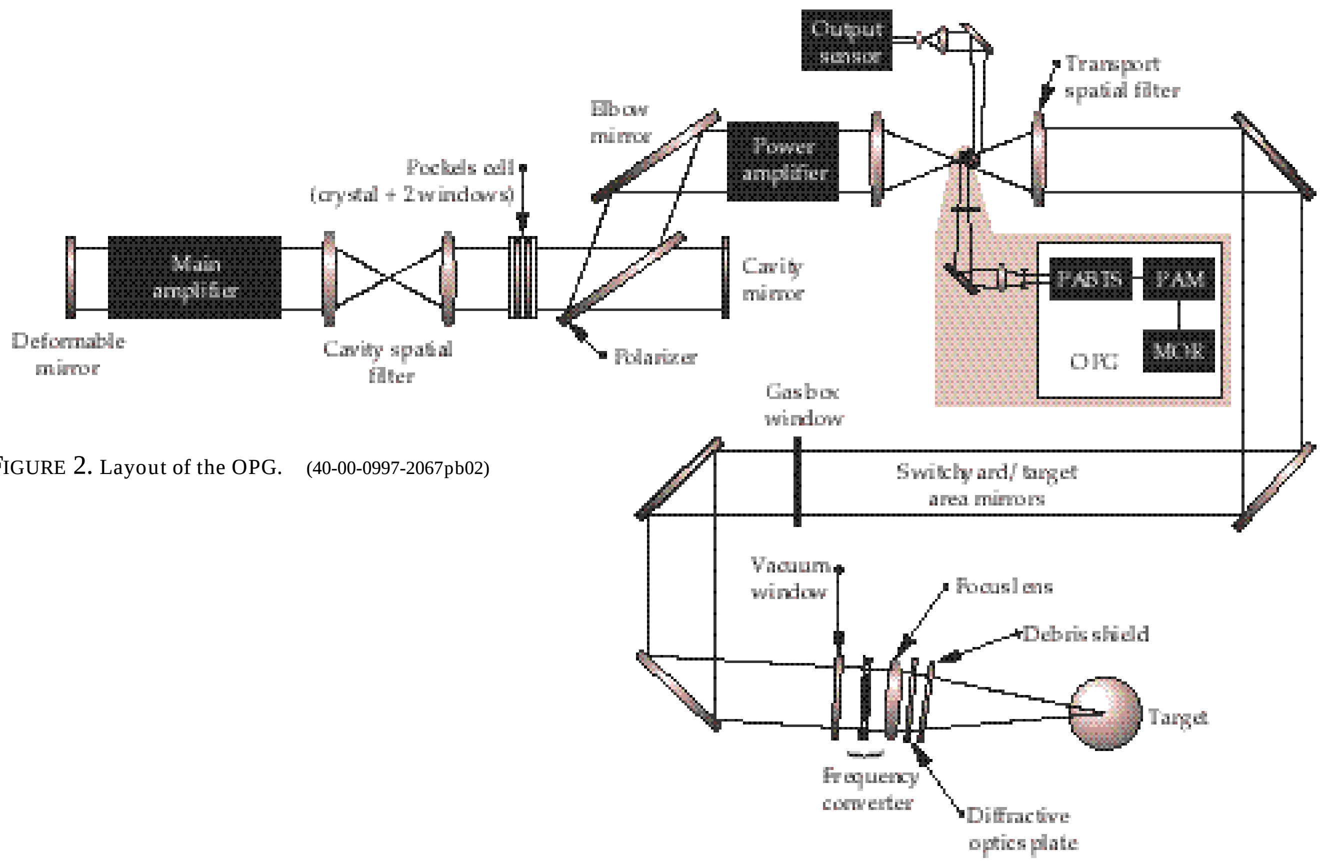


FIGURE 2. Layout of the OPG. (40-00-0997-2067pb02)

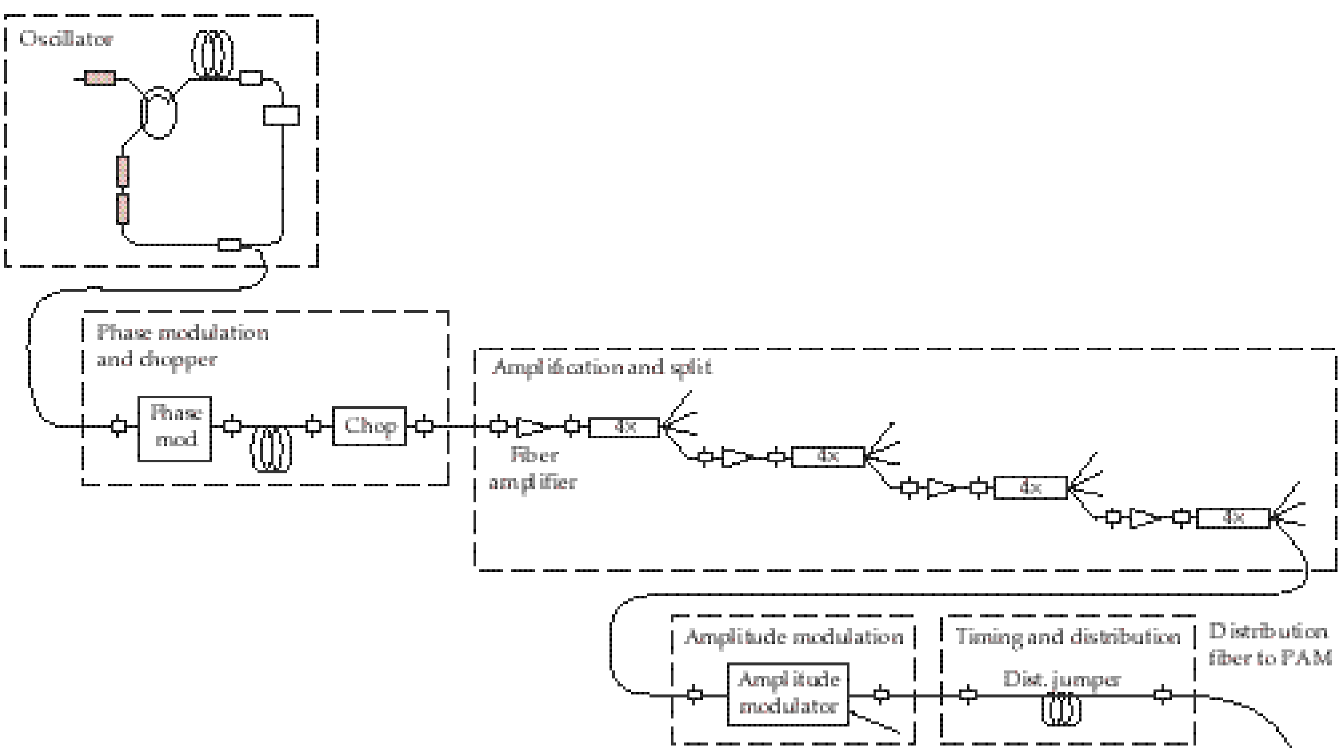


FIGURE 3. The NIF MOR design consists of fiber-optic subsystems in an optical series. (40-00-0997-2102pb01)

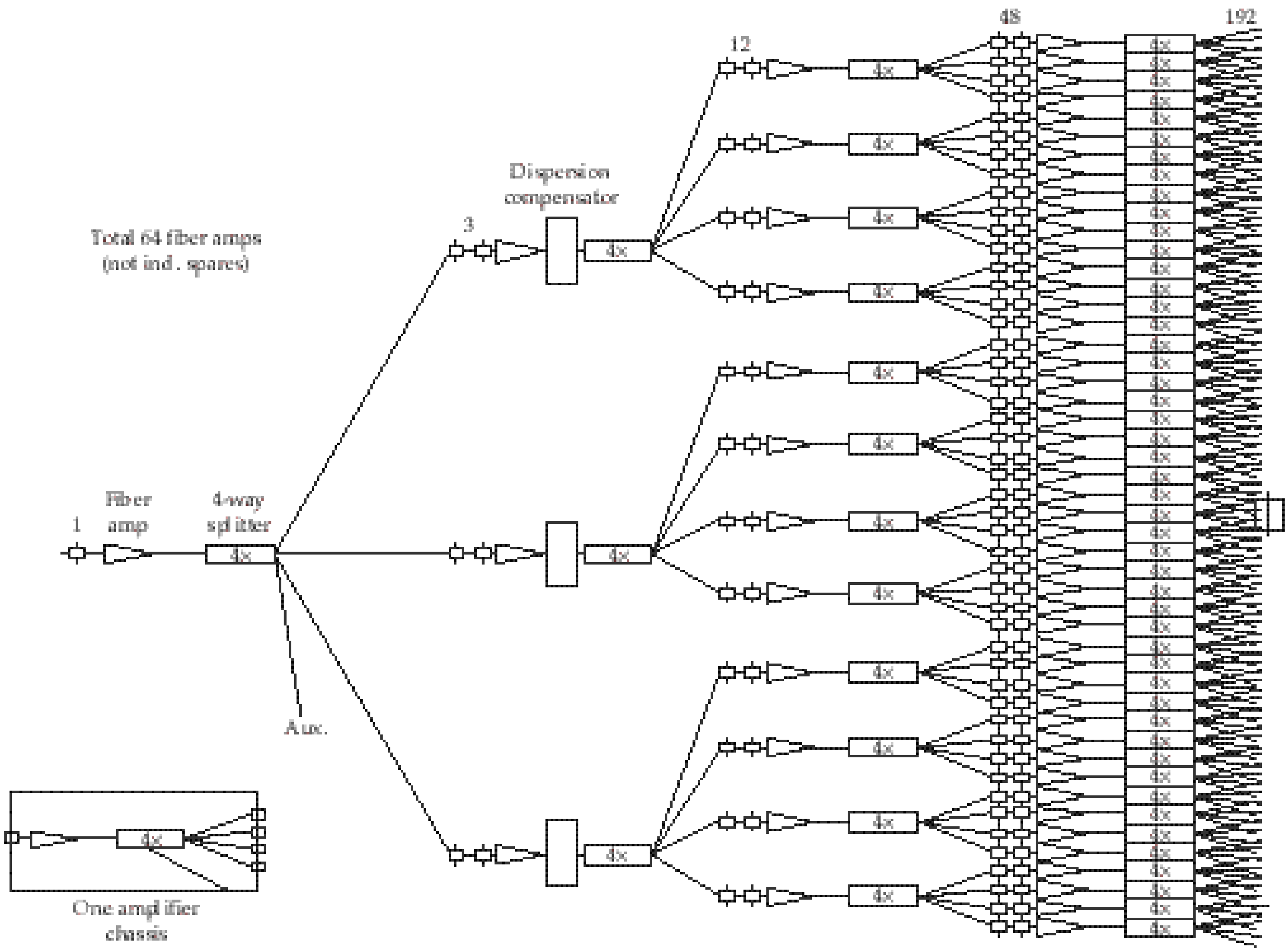


FIGURE 4. Amplifier array for 192 modulators showing dispersion compensators. (40-00-0997-2103pb01)

Each PAM is a line-replaceable unit, providing energy amplification on the order of 10^{10}, spatial shaping, and optional 1D beam SSD for one laser pulse. The PAM is a complicated system comprising the fiber launch, the regenerative amplifier, a beam shaper, the SSD, and a multipass amplifier (Figure 5). The fiber launch takes the MOR fiber-optic output, generates a Gaussian beam, 1.72 mm ($1/e^2$) diameter, and injects that beam as a seed pulse into the regenerative amplifier. Within the regenerative amplifier, the beam's energy is amplified to ~30 mJ using two diode-pumped rod amplifiers. The beam shaper transforms the Gaussian beam's spatial profile as it passes through an expansion telescope, an anti-Gaussian filter, and a quadratic filter, producing a nominally flat-top, 22.5-mm-square output beam. The beam then passes through a serrated aperture at relay plane 0 (RP0) before proceeding to the SSD subsystem. The SSD subsystem modulates the beam's propagation angle according to the frequency modulation previously imparted on the pulse in the MOR. The current 1D design is such that 2D SSD can be added later, if required. The multipass amplifier provides a 1.2×10^3 gain, increasing the pulse energy to 12.5 J, and uses relay imaging to control the beam's diffraction and walk-off.

Once the pulse leaves the multipass amplifier, it enters the optics that transport a small sample of the beam to the input sensor (see "Laser Control Systems" on p. 180 for the design of the input sensor). The majority of the beam then enters the PABTS, which primarily provides optical relaying and isolation (Figure 6). It optically links the PAM to the beam transport of the transport spatial filter using fully enclosed, nitrogen-filled beam tubes, and it provides an optical output that matches the requirements of the laser optical system. Its vacuum relays (relay telescope #1 and #2) carry the image of the RP0 from the PAM to the spatial filter.

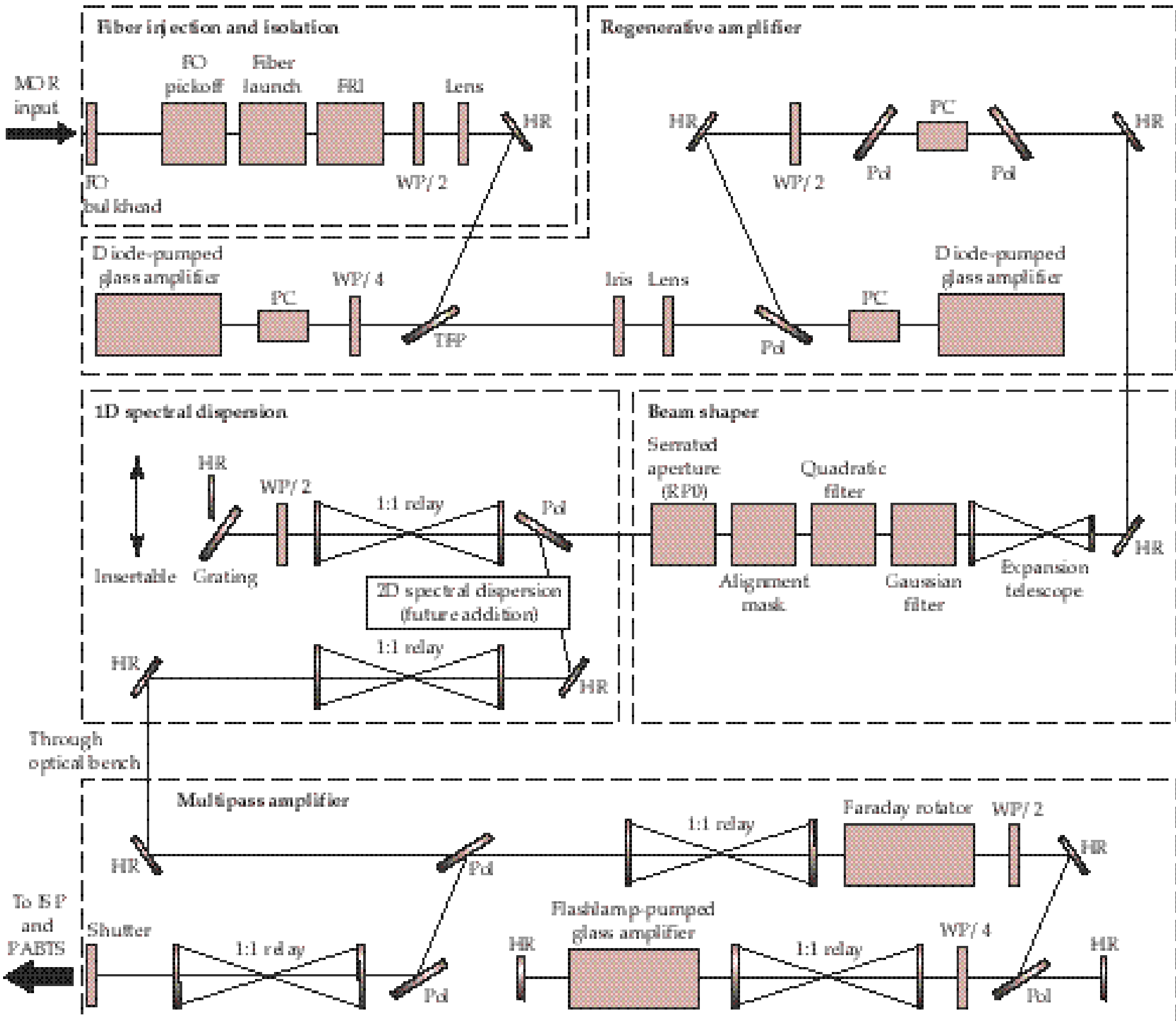


FIGURE 5. Five major sections comprise the PAM optical system. (40-00-0997-2104pb01)

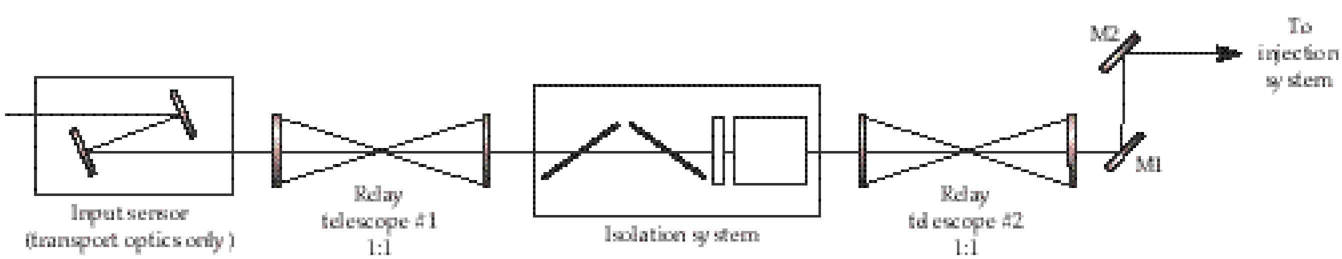


FIGURE 6. The PABTS comprises transport, relay, and back-reflection optics from the input sensor to the TSF support structure. (40-00-0997-2105pb01)

Between the two relays, an isolation system—consisting of two polarizers, a half-wave plate, and a permanent-magnet Faraday rotator—protects the PAM from back reflections of up to 25 J. Once the pulse leaves the second relay telescope, it exits the PABTS and enters the injection system.

The injection system, which comprises a telescope of two fused-silica elements and the injection mirror, focuses the beam into TSF pinhole #1 and projects the relay plane 16,805 mm past the SF3 lens of the TSF. The telescope design satisfies optical requirements and packaging constraints, and uses spherical fused-silica elements.

Title II Activities

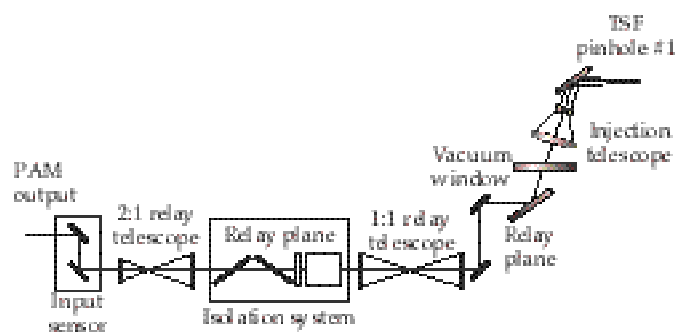
During Title II, we will implement the change from 192 PAMs to 48 PAMs. The split to 192 beamlines will occur in the PABTS, using a 1:4 splitter that is under design (see “Conceptual Design for a 1:4 Beam Splitter in the Preamplifier Beam Transport System” below). We will complete the detailed design of the OPG in Title II, reducing the number of optics where possible. We also will extensively test prototypes and integrated systems operations.

Amplifier System

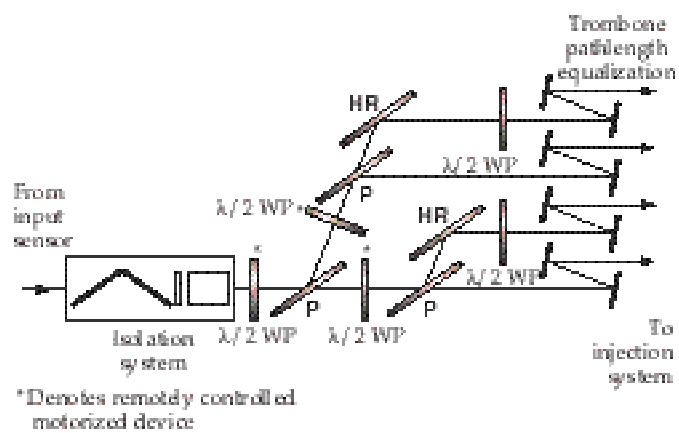
This section focuses on the two large amplifiers in the NIF laser cavity—the main amplifier and the power amplifier (Figure 7). The functions of these amplifiers are

CONCEPTUAL DESIGN FOR A 1:4 BEAM SPLITTER IN THE PREAMPLIFIER BEAM TRANSPORT SYSTEM

Since mid-Title I, we have changed the architecture to reduce costs and still meet the required laser performance. As part of that change, we are reducing the number of preamplifier modules to 48, with the final split to 192 beamlines occurring in the preamplifier beam transport system (PABTS), instead of in the master oscillator room as set out in the Title I design. We have come up with a conceptual design showing that a 1:4 beam split is feasible in the existing PABTS layout, with some modification in the injection telescope. The split would follow the isolation system, in the area where the second 1:1 relay telescope and two mirrors appear in the Title I design (see figure at right). In the splitter design, the 48 pulses are split twice, using half-wave plates, polarizers, and mirrors. Most of the half-wave plates are motorized and remotely controlled so that we can continuously adjust the energy throughput. The path lengths are equalized using trombones, and the individual beam energies monitored at the output sensor packages. This design allows us to meet packaging requirements and keeps the cost down with a minimum of optical elements. In early Title II, we will continue to study and develop the 1:4 splitter section and modify the injection telescope as required.



The 1:1 relay telescope and injection telescope design can be modified to accommodate additional path length for the splitter. (40-00-0997-2120pb01)



The 1:4 conceptual design matches path lengths to maintain relay imaging and provides remote continuous adjustability of energy throughput. (40-00-0997-2121pb01)

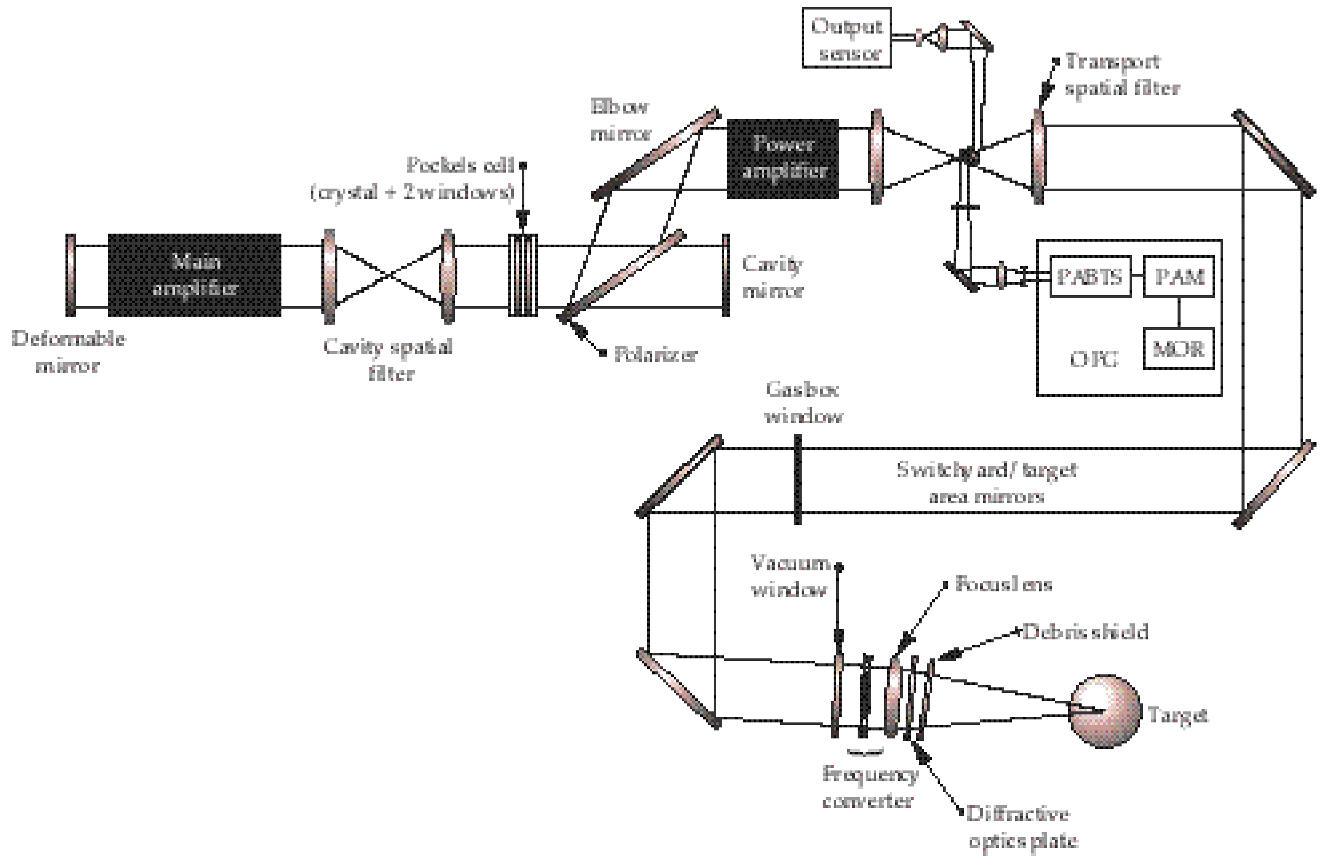


FIGURE 7. The main amplifier and power amplifier are parts of the main laser cavity. (40-00-0997-2067pb03)

to efficiently amplify the 1ω input pulse to its required power and energy, as well as to maintain, within specified limits, its pulse shape, wavefront quality, and spatial uniformity. We also had to design a clean, mechanically stable housing, called the frame assembly unit (FAU), that allows the amplifiers' LRUs to be replaced rapidly without disrupting adjacent components.

The amplifiers are located in the Laser and Target Area Building (LTAB), adjacent to the four capacitor bays (Figure 8). One of the major design challenges for the amplifiers was minimizing their volume to save space in the LTAB while still satisfying requirements. The following discussion summarizes the preliminary design features of the amplifiers, including the optical pump cavity, the bundle configuration, the cluster configuration, and the flashlamp cooling system. (For information about the optical design of the amplifier slabs, see "Optical System Design" on p. 112.) The support structure for the amplifiers, power cables, and utilities are discussed in the article "Beam Transport System" (p. 148).

The NIF amplifiers have a compact pump-cavity design with shaped reflectors. Figure 9 shows a cross section of the optical pump cavity of a one-slab-long segment. The cavity includes two types of LRUs—a slab cassette and a flashlamp cassette— shaped reflectors, and antireflection-coated blast shields. The glass slabs in the slab cassette are 4.1 cm thick and have an Nd-doping concentration of 3.6×10^{20} ions/cm^3. NIF has a total of 7680 large flashlamps; each amplifier has six flashlamps in two side arrays and eight flashlamps in a central array. These flashlamps are larger and less expensive than those used in previous ICF solid-state lasers (Table 1). The compactness of these amplifier units is limited by NIF's mechanical design requirements, including the requirements for stability, insertion clearances for the LRUs, and the seals.The side flashlamp cassettes have involuted reflectors, which improve pumping efficiency by reducing light reabsorption by the flashlamps. For the central flashlamp cassettes, skewed diamond-shaped reflectors improve gain uniformity by directing pump light to selected regions of the slab. Figure 10 shows the seven components, or basic building blocks, that comprise one amplifier assembly. The LRUs and blast shields slide into FAUs, which come in configurations of 4 × 2 × 2 and 4 × 2 × 3.

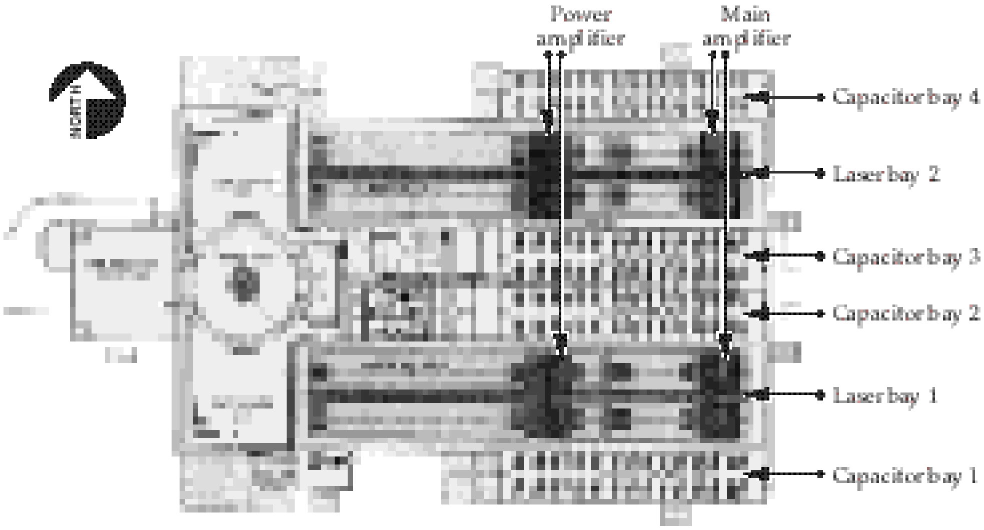


FIGURE 8. The main and power amplifiers are located in the LTAB (plan view). (40-00-0997-2107pb01)

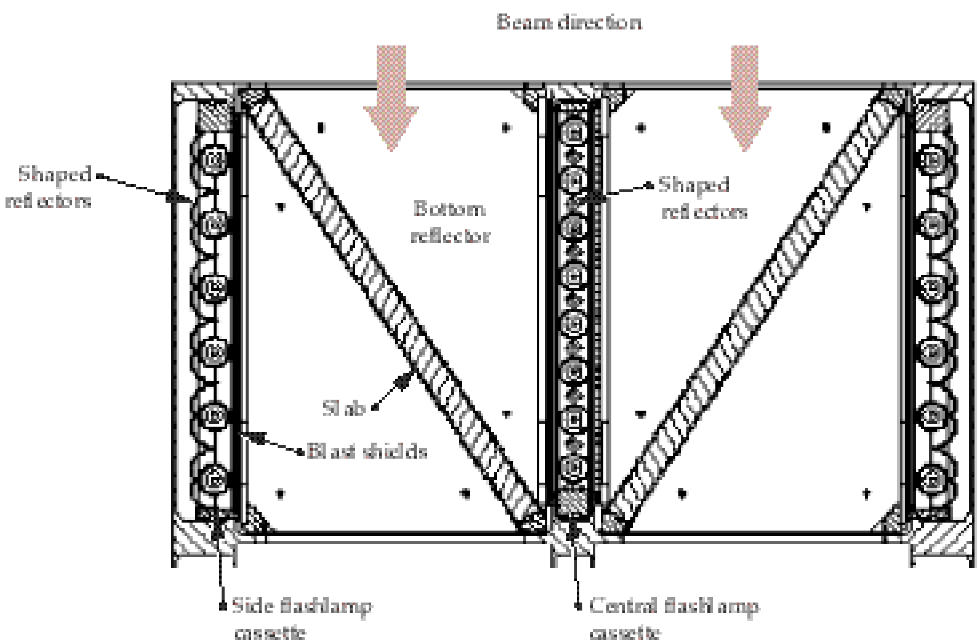


FIGURE 9. Each amplifier has a glass slab cassette, a side flash-lamp cassette, and glass blast shields with antireflection coatings. A central flashlamp cassette runs between two beamlines. (40-00-0997-2108pb01)

TABLE 1. Flashlamp parameters for ICF solid-state lasers.

	Nova	**Beamlet**	**NIF**	**LMJ**
Number	5000	512	7680	~10,800
Bore diameter (cm)	2	2.5	4.3	4.3
Arc length (cm)	48	91	180	180
Energy / lamp (kJ)	6	12	34	34
Cost / kJ	~$100 / kJ	~$70 / kJ	$38 / kJ	—

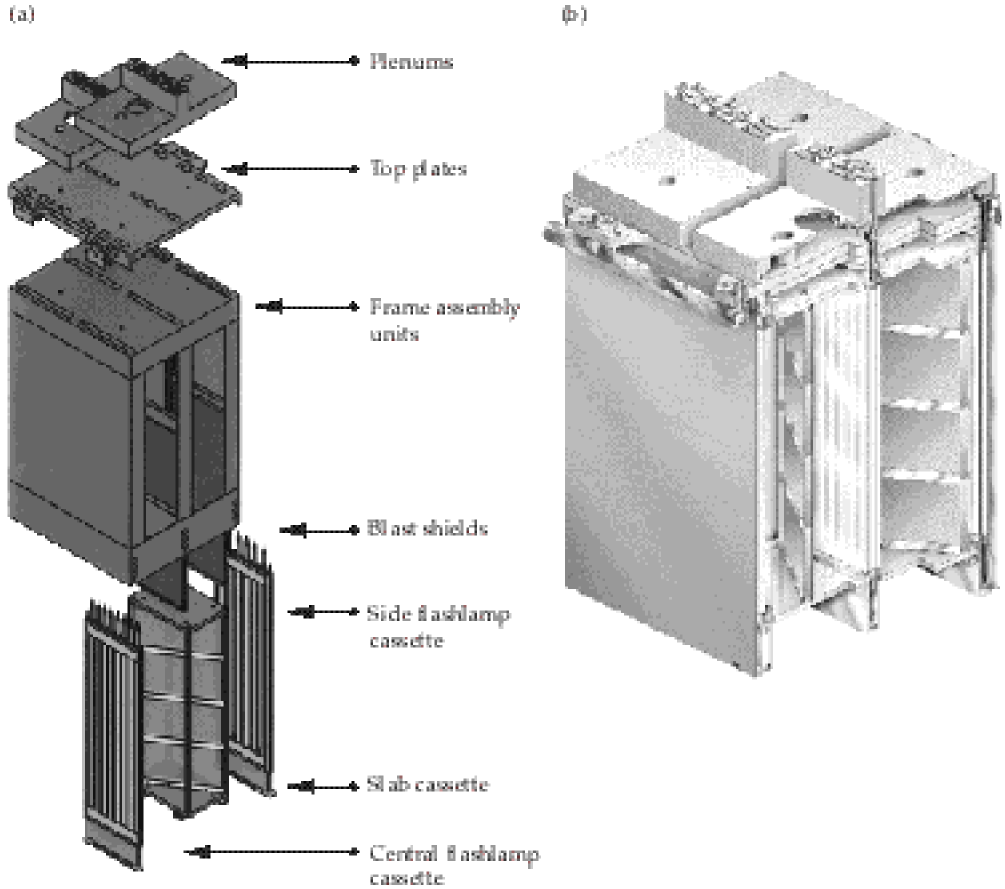


FIGURE 10. (a) Each amplifier is assembled from interchangeable "building blocks": a plenum, top plate, frame assembly unit (FAU), blast shields, a side flashlamp cassette, a slab cassette, and a central flashlamp cassette. The cassettes slide into the FAU, and the FAU and blast shields are removable as well. The plenum and top plate are "fixed" to the structural support. (b) A 4 × 2 × 2 amplifier FAU for eight beamlines. (40-00-0997-2110-pb01)

Bundles in the main and power amplifiers include both FAU configurations, as well as other components (Table 2). The bundle, which contains eight beams, is the minimum amplifier operating unit. Each bundle is environmentally sealed from the laser bay and operates independently. Each bundle provides a common amplifier electrical ground, common flashlamp cooling distribution, and a common slab cavity atmosphere.

The amplifier cluster consists of six tightly packed bundles. Table 3 shows the parameters of the two clusters that appear in each of the four laser bays. The cluster configuration allows us to balance many requirements, including minimizing bundle spacing and height to reduce LTAB costs, providing bundle electrical ground isolation to 25 kV, and permitting amplifier cassette LRUs to be loaded from the bottom and clean amplifier bundles to be installed from above.

To meet the requirement of one shot every eight hours, the flashlamps are air-cooled at 20 cfm / flashlamp for 6 to

TABLE 2. Bundle components and parameters.

Components in a bundle	Main amplifier (11 slabs)	Power amplifier (5 slabs)
4 × 2 × 2 FAU enclosure	4	2
4 × 2 × 3 FAU enclosure	1	1
FAU mating flange	4	2
End isolators	2	2
Blast shields	44	28
Slab cassettes	22	10
Flashlamp cassettes	33	15
Flashlamps	220	100
Distribution plenums	11	7
Top plate assemblies	5	3

TABLE 3. Cluster components and parameters.

Quantity in each laser bay (i.e., 2 clusters)	Main amplifier	Power amplifier
Number of slabs long	11	5
Number of slabs	1056	480
Number of flashlamps	2640	1200
Number of blast shields	528	336
Number of bundles	12	12
Overall width (mm)	2390	2390
Overall length (mm)	11,074	8034
Centerline above floor	4572	6987
Assembled weight (kg)	110,000	70,000
Bank energy (MJ)	106	48
Cooling gas flow (cfm)	26,400	14,000

7 hours. We chose air instead of nitrogen as the cooling gas to meet cost objectives and have a plan for dealing with the possible degradation of the flashlamps' unprotected silver reflectors.

Title II Activities

During Title II, we will finalize the details of the amplifier design and continue testing prototypes in the LLNL's AMPLAB. We are about to begin the final design of the slab and flashlamp cassettes. The potential risk areas for the cassette designs were identified during prototyping, and we will resolve those risks in the AMPLAB amplifier prototype. Among those risks are flashlamp reliability, thermal recovery, and optical performance. We plan to reduce the costs of these cassettes by simplifying the designs (i.e., combining parts and using part features such as shape, tolerance, and finish).

NIF flashlamps will work as required, but we need to develop them further to meet NIF's failure rate requirements. During Title II, our prototype flashlamps will undergo a 200-flashlamp, 10,000-shot test to qualify vendors. We will also continue thermal tests to demonstrate the air-cooling technology we have chosen for cooling the flashlamps. We will also address the degradation of the silver plate on the flashlamp reflectors that arises from air cooling. We have three possible approaches that we will be exploring during Title II. First, we could overcoat the silver with a protective layer or use an alternative, more stable, reflector material. Second, we could clean the air before it is injected. Third, we could revert to nitrogen cooling.

We will also change the FAU design to increase the rigidity and provide greater design flexibility for the FAU joints. As part of that redesign, the blast shield seal will become a mechanical seal, with a hard-mounted joint. During Title II, we will also choose what glass and antireflection coating to use for the blast shields.

Power Conditioning System

The Title I design for the power conditioning system, which provides energy to the 7680 flashlamps in NIF's amplifiers, is driven by these key laser system design requirements:

- Performance requirements. The laser system must deliver to the target 1.8 MJ in 3ω, with an rms deviation of <8% in the power delivered by each beam.
- Operational requirements. The laser system must have a shot-turnaround time of eight hours, not to preclude a four-hour turnaround, and must be able to fire an arbitrary subset of bundles on each shot.
- Reliability / availability / maintainability requirements. The laser system must have a lifetime of 30 years, shot availability of at least 97.44%, an overall reliability of 82.66%, and no more than 6.8 unplanned maintenance days per year.

The amplitude, pulse shape, and timing of the power delivered by the power conditioning system to the flashlamps depend on the required amplifier gain (see Figure 11). We derived the nominal output specifications for the power conditioning system, based on an average gain coefficient of 5.0% / cm. Using computer models, we determined that the power conditioning system's main pulse must deliver 34 kJ / flashlamp in a critically damped pulse 360 μs long, the preionizing pulse must deliver no less than 500 J / flashlamp in a critically damped pulse 120 μs long, and the energy variations between flashlamps must be less than ±3% rms.

The resulting Title I design for the NIF power conditioning system is a product of the collaborations of LLNL, Sandia National Laboratories (SNL), and industry. In this design, the system occupies four capacitor bays adjacent to each laser cluster (Figure 12). Each capacitor bay contains 48 500-kA "bank modules," which feed one amplifier cluster (Figure 13). Eight modules are needed to power each laser bundle

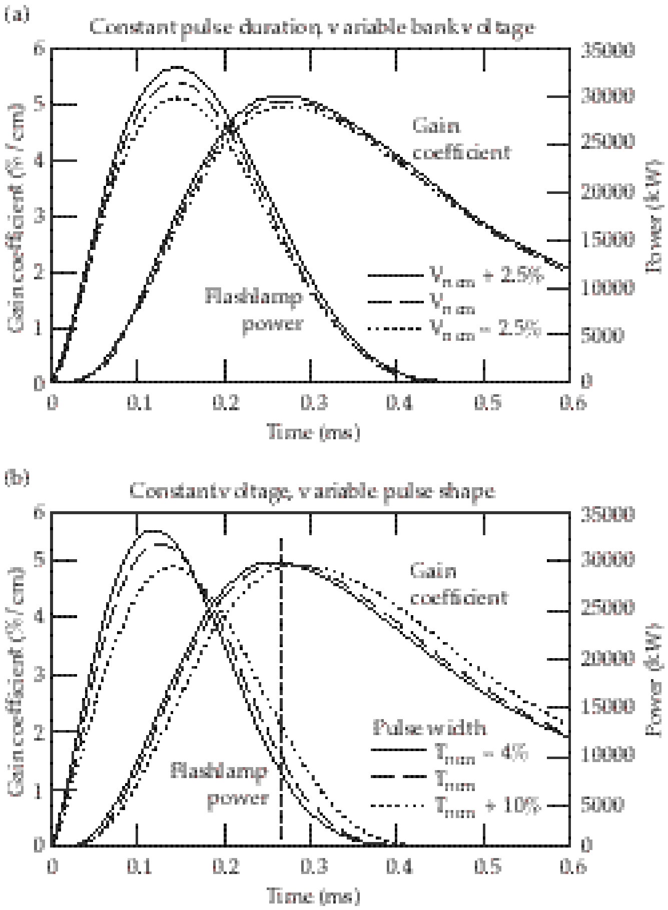


FIGURE 11. Amplifier performance calculations are used to predict the allowable tolerance on the pulsed power output to meet the NIF power balance requirements. (a) Shows a variation in amplitude; (b) shows variations in pulse shape and timing. (40-00-0997-2111pb01)

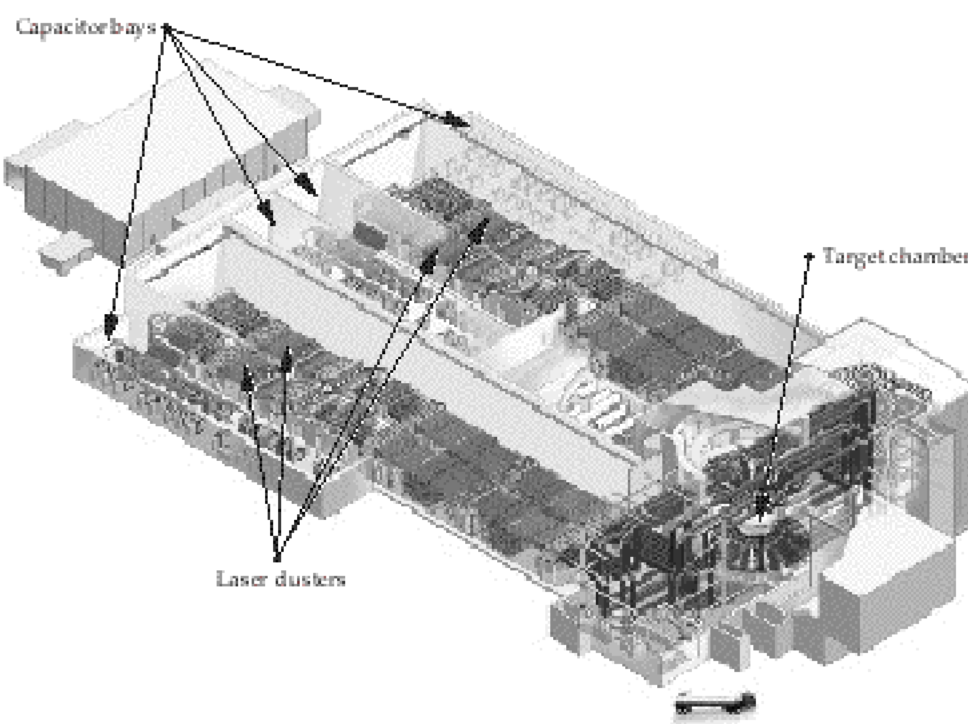
(see "How Big a Bank?" next page). These bank modules are the heart of the power conditioning system. Each module has a preionization system, a capacitor bank, a switch / ballast assembly, and controls / electronics, and can drive 40 flashlamps configured as 20 series pairs.

A module must deliver three pulses to each flashlamp: a trigger pulse on the order of several kV / µs to trigger the flashlamps, a 500-J, 120-µs preionization pulse, and a 34-kJ, ~360-µs main pump pulse with a peak current of 25 kA to each pair of flashlamps in a series. Two independently switched circuits—one in the preionization bank, the other in the main bank—generate the required flashlamp excitation. Either bank can supply a trigger pulse to the system. During normal operation, the preionization bank supplies the trigger; in a main switch prefire, the main bank delivers the trigger.

For the preionization pulse, a small (30×30-in.^{2}) single-capacitor bank delivers the preionization pulse by coaxial cable to the 40 flashlamps. This small bank consists of a single 100-µF, 30-kV metallized film capacitor; a small, independent charging supply; a sealed gas or vacuum switch; a fuse to isolate it from the main bank; a pulse-shaping inductor; and a dedicated dump circuit. The circuit for this bank comes packaged as a preassembled unit. The bank also has a ballast system, which forces current sharing in the event of a shorted or an open-circuited flashlamp.

A large ($7 \times 5 \times 8$ ft^3), 20-capacitor bank delivers the main current pulse to the flashlamps via coaxial cables roughly 300 µs after the beginning of preionization.

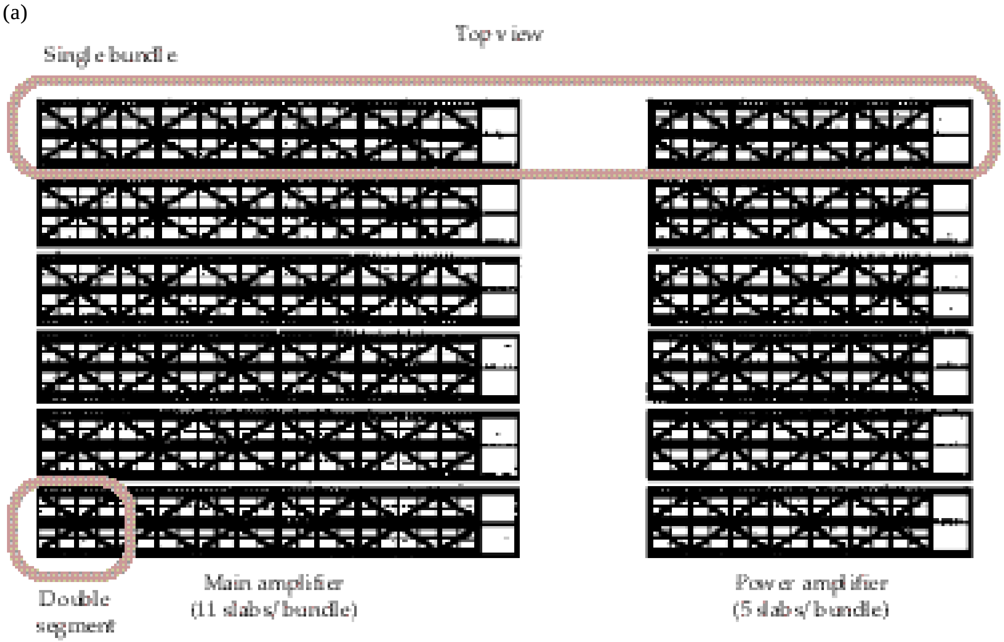
FIGURE 12. Location of the power conditioning system. (40-00-0997-2112pb01)



HOW BIG A BANK?

We determined the size of each individual bank module by examining the trade-offs between cost and performance risk. Larger modules reduce the total cost of the system by reducing the number of power supplies, triggers, controllers, and so on. However, the module size is limited by the availability of reliable, high-current switches. Our preliminary design features a 500-kA switch, which balances cost and performance risks and is a reasonable extrapolation from commercial devices now available.

(a)



(b)

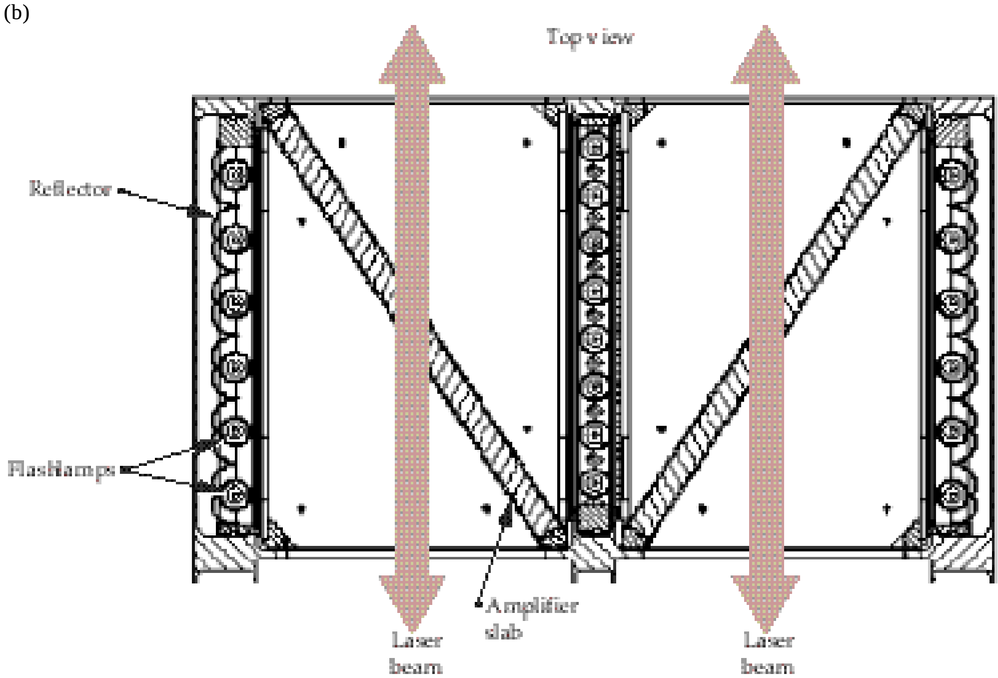


FIGURE 13. (a) A top view of one amplifier cluster, including both the main amplifier and power amplifier. Each cluster contains six bundles of 16 amplifier slabs (11 slabs from the main amplifier and 5 from the power amplifier). (b) The insert shows a scaled-up view of a single 4 × 2 section of a bundle, with 20 flashlamps arranged in 10 series pairs.
(40-00-0997-2113pb01)
(40-00-0997-2114pb01)

This large bank consists of 290-μF, 24-kV metallized film capacitors, an independent 25-kW charging supply, a pressurized spark gap, pulse-shaping inductors, dedicated redundant dump circuits, and a ballast system similar to that for the preionization bank.

Each transmission line consists of a bundle of RG-220 coaxial cables. We have 22 cables per bundle: 20 to feed the flashlamp circuits, 1 as a return of reflector fault current, and 1 spare.

Our present design satisfies voltage, energy, and pulse-width requirements. However, using simple models to determine the flashlamp load, we determined that a 90%-efficient preionization circuit is underdamped. Final circuit parameters will be determined in Title II.

Each of the four capacitor bays can be viewed as a "stand-alone" system. The 48 1.6-MJ modules are configured in doublets for seismic stability and access. We have 30 full modules feeding the main amplifier, 12 feeding the power amplifier, and 6 feeding flashlamp cassettes in both amplifiers. The modules are configured such that space is available for more, should the power amplifier be upgraded to a 7-slab configuration. Each bay has a 13.8-kV substation to supply 480 VAC charging power, and each module has its own 100-A circuit breaker. Each bay also has a single front-end processor for communications to and from the NIF control room, as well as its own gas, water, and pressurized air manifolds.

Title II Activities

In our future activities, we have identified several challenges, but see no show-stoppers. For the switching, we have identified a feasible candidate, the Physics International ST-300 spark gap. We will obtain data on switch lifetime, reliability, and performance from SNL's switch test facility, and will continue to investigate other technologies as well. For the capacitors, at least three vendors are pursuing technology enhancements to reduce the costs. The flashlamp operation is well characterized; in Title II, we may recommend some enhancements to increase the safety margin. The design of the power conditioning system module will be refined to further optimize cost and performance, and the final design will be thoroughly demonstrated in experiments on SNL's prototype test bed before construction begins.

Plasma Electrode Pockels Cell

The Pockels cell, located between the cavity spatial filter and the polarizer in the main laser cavity of NIF (Figure 14), rotates the polarization of light transmitted through the cell and works with the polarizer to act as an optical switch. This configuration allows the laser pulse to gain energy efficiently by making multiple passes through the main amplifier (Figure 15). To meet NIF requirements, this Pockels cell must have a 100-ns rise time and a 150-ns flat-top pulse shape, and its switching efficiency must be >99% for both "on" and "off" states.

We are using an LLNL-developed plasma electrode Pockels cell (PEPC), which has distinct advantages over conventional Pockels cells (see "Why a PEPC?" below). We have successfully used this PEPC design for a 37-cm-aperture Pockels cell on Beamlet for two years, with no missed shots. Electrically, the PEPCs are two independent 2 × 1 Pockels cells, back to back. Mechanically, the NIF PEPCs are designed as a 4 × 1 LRU that can be bottom-loaded into the periscope structure.

WHY A PEPC?

Pockels cells use electrically induced changes in the refractive index of an electro-optic crystal, such as KDP, to rotate the polarization of light when an electric field is applied along the direction in which the light beam propagates. Conventional ring-electrode cells have high damage thresholds, but require a crystal that is about the same thickness as the beam diameter. A crystal this thick is completely impractical for the NIF's 40-cm beam. Some cells use transparent, conducting films as electrodes, but these have questionable damage thresholds and a high surface resistivity, which causes slow and nonuniform switching.

For NIF, we are using the plasma electrode Pockels cell (PEPC) developed at the LLNL. As shown in Figure 17, a thin plate of KDP is sandwiched between two gas-discharge plasmas. The plasmas serve as conducting electrodes, allowing us to charge the surface of the thin crystal plate electrically in ~100 ns with very high uniformity. These plasmas are so tenuous that they have no effect on the high-power laser beam passing through the cell. The damage threshold of the KDP crystal is unaffected by the plasma or electrical charge.

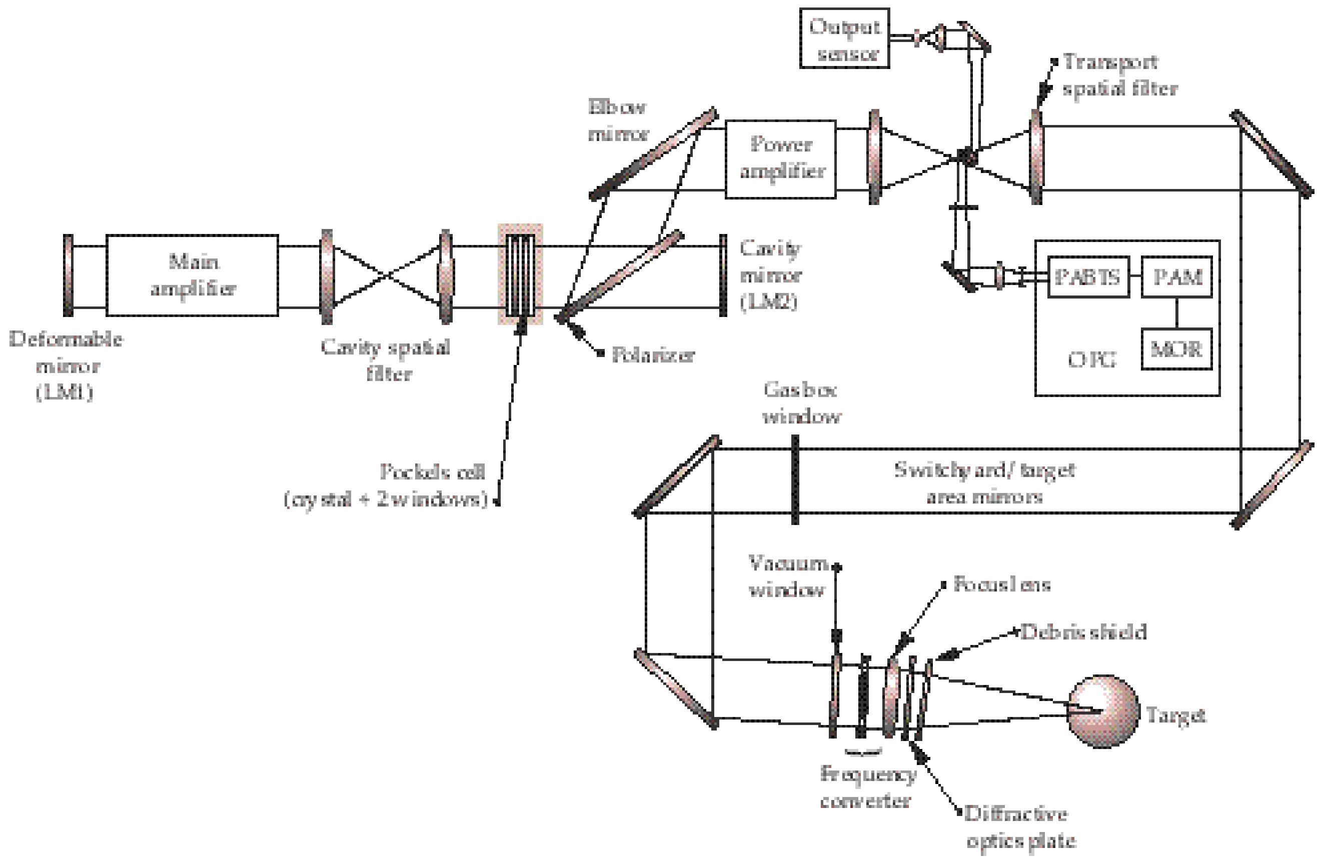


FIGURE 14. Location of the NIF Pockels cell in the beamline (shaded area). (40-00-0997-2067pb04)

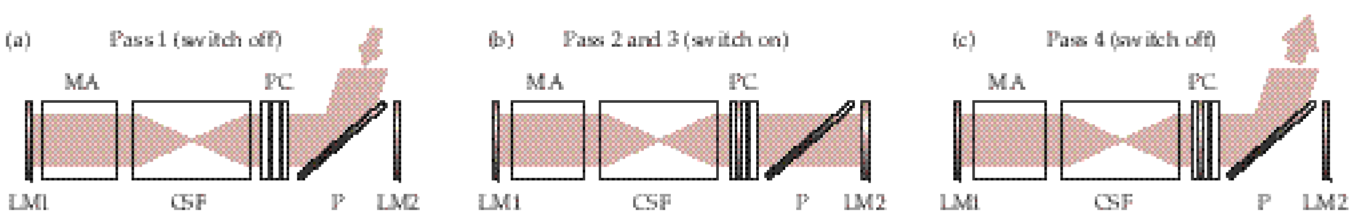


FIGURE 15. The Pockels cell and polarizer work as an optical switch to trap the pulse in the cavity between LM1 and LM2 for four passes, as follows. (a) When the cell is "off," the cavity is open and the beam is injected into the cavity between the deformable mirror, LM1, and the cavity mirror, LM2. (b) When the cell is "on," the cavity is closed and the beam multipasses between LM1 and LM2, through the main amplifier, for four passes. (c) On the fourth and final pass, the cell is switched off, allowing the pulse to switch out of the cavity. (40-00-0997-2116pb01)

The PEPC is a complex opto-mechanical-electrical system including a gas cell, switch pulsers, plasma pulsers, and controls and diagnostics, as well as vacuum, gas, and structural subsystems (Figure 16). In this section, we focus on the design of the pulsers and the gas cell, while briefly addressing the vacuum and gas subsystems and structural design of the housing and window. An overview of controls and diagnostics appears on p. 180 of this *Quarterly*; more information on the structural design of the periscope structure appears in the article "Beam Transport System" (p. 148).

The PEPC is driven by three pulse generators, shown in Figure 17. In each PEPC, two plasma pulsers drive several kiloamperes of discharge current through a low-pressure helium background to create conductive and transparent plasma electrodes. The switch pulser can charge the KDP crystal to a V_π of about 17 kV or discharge it from V_π back to zero volts in ~100 ns,

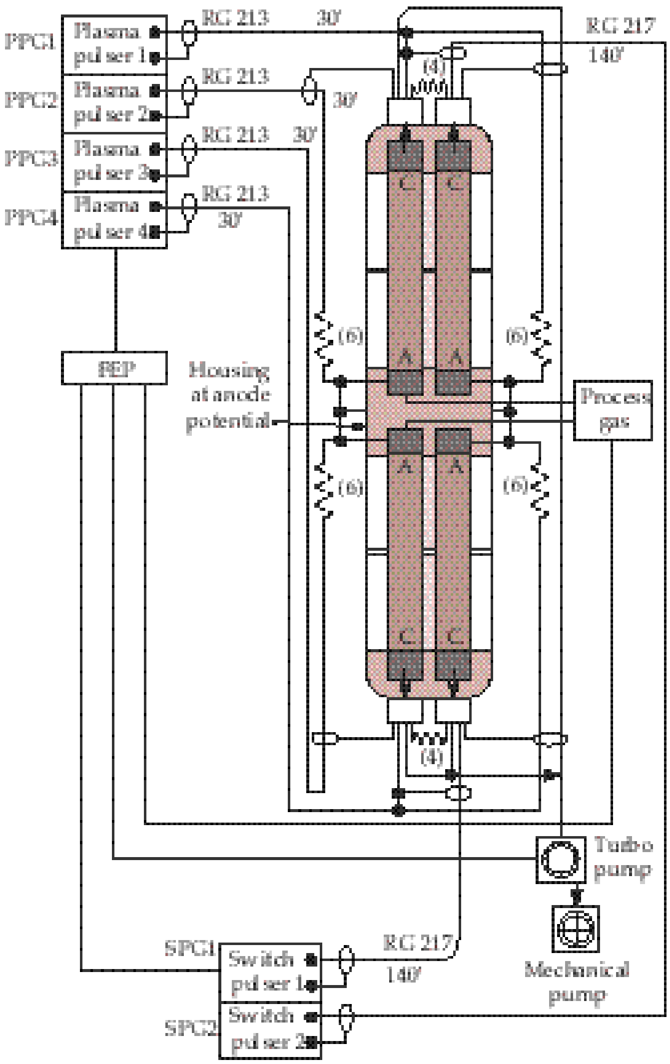


FIGURE 16. The PEPC subsystem schematic. (40-00-0997-2117pb01)

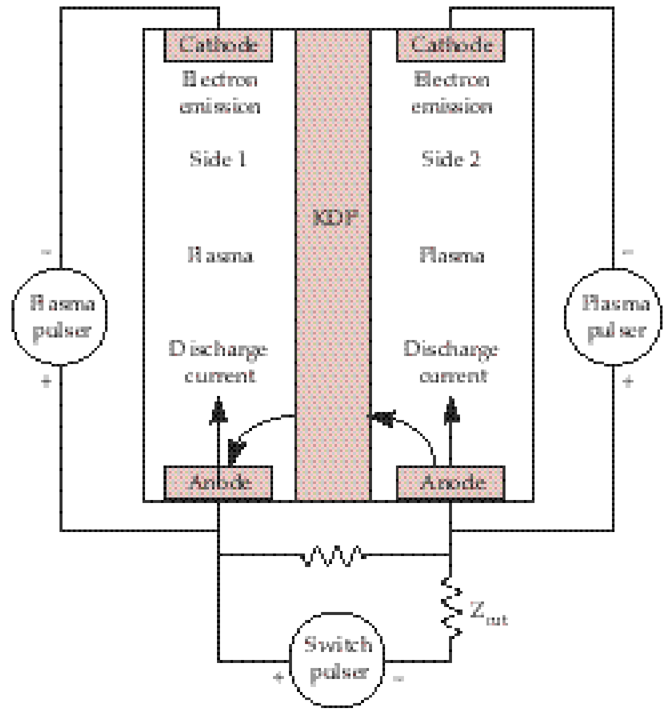


FIGURE 17. The PEPC includes a KDP crystal, two plasma pulsers, and a switch pulser. (40-00-0997-2118pb01)

where V_π is the voltage required to rotate the polarization through 90°. Each 4 × 1 LRU requires two switch pulsers and four plasma pulsers, designed to meet NIF optical switching and reliability, availability, and maintenance requirements. The "on" pulse length is determined passively by an electrical transmission line, which gives very high reliability for the cavity switchout. This is a "fail-safe" feature to protect the laser components in the cavity. Each plasma pulser generates a discharge that spans two apertures on one side of the midplane assembly. The NIF switch pulser and plasma pulser circuits are similar to the Beamlet design but are being reengineered and packaged for low cost and high reliability by Titan-Beta Corporation.

The gas cell integrates several subassemblies and optical elements, including housings, switch windows, a midplane assembly, an anode assembly, a cathode assembly, and a vacuum plenum / baffle assembly (Figure 18). The cell is designed to meet NIF's optical and cleanliness requirements, beam spacing requirements, and the requirement to provide a switching efficiency >99%. To meet the spacing requirement, we designed a compact 4 × 1 LRU with insulated aluminum housings, an external frame, and square-edged windows. We also designed the anodes to be back-to-back at the midpoint of the housings and the cathodes, which are larger, to be at the top and bottom of the housings. To meet the switching efficiency, we optimized the plasma channel design to achieve uniform plasma for switching, and optimized the vacuum pump and gas control systems as well. To minimize static birefringence, we designed a rigid aluminum housing with a precise window–housing interface.

Our Title I PEPC 4 × 1 housing design is based on anodized aluminum construction, and is designed to meet NIF mechanical, electrical, and vacuum requirements at minimum cost. The structural integrity of the housing design is verified by finite-element analysis. The housing and window are designed to minimize shear stress in the window. The PEPC window is a rectangle, 3.5 cm thick, with a tensile stress below 700 psi. The midplane assembly that holds the crystals is 13-mm-thick borosilicate float glass and provides adequate electrical insulation for the PEPC switch operation and low outgassing (< 7.4×10^{-9} Torr-L / s-cm^2) per NIF requirements.

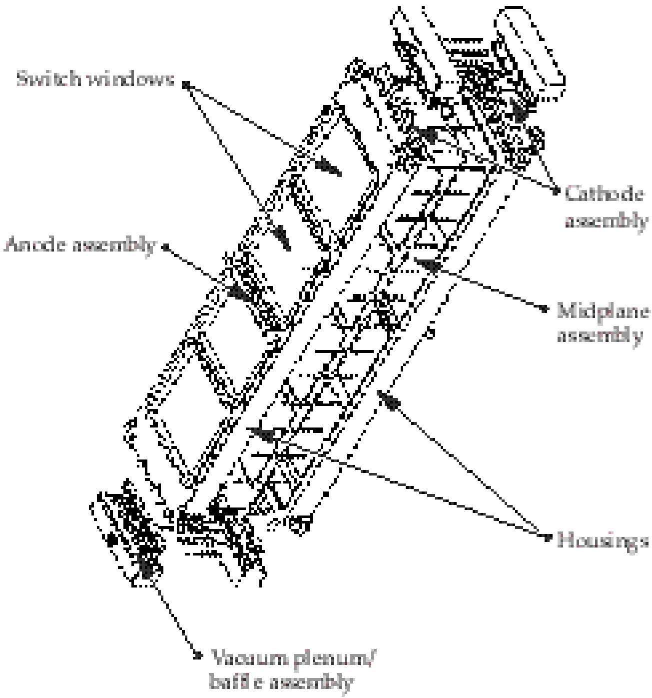


FIGURE 18. Configuration of the PEPC gas cell. (40-00-0997-2119pb01)

The PEPC cathode and anode structures exposed to the plasma are faced with pyrolitic graphite. This facing ensures that any material sputtered from these electrodes will react with the oxygen in the process gas (helium plus 1% O_2) to form CO and CO_2, which are removed by the pump system. This reaction prevents sputtered material from depositing on the crystal or window surfaces. The anode is segmented into six individually ballasted "buttons" to force the plasma to be uniform across the width of the discharge. Process gas enters through ports at the anode. The hollow-cathode assembly contains the vacuum ports and connects to a vacuum baffle structure that prevents discharge current from running through the vacuum lines to other locations.

The gas and vacuum system for each LRU has individual vacuum plenums for each plasma channel. These connect to a vacuum manifold evacuated by a turbomolecular drag pump that is part of the LRU. Foreline pumping is by connection to a foreline pumping system in the laser bay. Each bay has two 50-cfm (cubic feet per minute) foreline pumps, located outside the LTAB on a utility pad. The gas flow at operating pressure (35 mTorr) is 0.23 Torr-L/s, and the base pressure is $< 5 \times 10^{-5}$ Torr.

Each plasma channel has an electrically controlled valve and pressure gauge that provides closed-loop control of the operating pressure through the integrated computer control system. The control system also monitors the electrical performance of each cell during operation to verify that all parameters are within preset limits.

Title II Activities

A 2 × 1 PEPC, now in construction, will test most of the key features of the NIF design and is the next step towards a full NIF prototype. We are using the 2 × 1 prototype to demonstrate the full-scale anodized aluminum housing, uniform switching of the two crystals, and uniform plasma production across the double aperture. In FY97, we plan to finish testing the 2 × 1, validate the 2 × 1 discharge, procure 4 × 1 parts based on the Title I design, and begin testing the assembled 4 × 1. We will use those test results to complete our Title II design early in FY98, then do detailed tests, including life evaluations. The results will be used to update the design for Title III.

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